Connections for Prefabricated Timber-Concrete Composite Systems

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Abstract

Timber-concrete composite beams and slabs require connectors, which provide high composite action in the section. For a rational and dry construction process it is interesting to investigate connections, which do not implicate the curing of concrete at the building site. This paper describes experimental studies on different mechanical “dry-dry” connectors (already embedded into a prefabricated concrete slab). Some new joining concepts consisting of shear connectors to connect glulam timber beam and concrete slab were investigated through shear or “push-out” tests. Shear tests were performed in 7 series of different connector types in order to obtain their load-slip relation with the aim of establishing composite action between the prefabricated concrete slab and the timber beam. The slip moduli and strength are presented and discussed in the light of mechanical performance.

Keywords: Composite structures, Timber-Concrete structures, Timber Joints, Mechanical connectors, Shear connectors, Composite Action

1. Introduction

Timber-concrete composite systems offer extensive variability of usage e.g. in floor structures or bridges. The advantages of using these composite structures compared to wooden floors are mainly the increase of load-carrying capacity and the improvement of acoustical and thermal properties of the system. The system is also applicable in renovating historical timber floors and for this particular purpose has become important on the European market. The structure, with wood resisting tensile forces, concrete slab resisting compressive forces and connectors carrying shear forces constructs a timber-concrete system competitive to either wood or concrete alone. The first principle to achieve strong, rigid and lightweight systems is to focus on the shear connector performance. Experimental studies performed by many researchers [1-5] introduced a broad range of fasteners and techniques to combine timber and concrete. To reach full composite action between wood and concrete epoxy adhesives or mechanical joints as grooves in timber can be used, while more ductile connectors made with steel fasteners as nails, screws etc. provide only partial composite action.

The vast majority of research has been performed on systems where wet concrete is cast on top of timber beams with mounted connectors. To make timber-concrete composite systems further competitive in the market it is worthwhile to develop a system speeding up production and reducing on-site costs. The shrinkage of concrete is also a pronounced problem in a wet-dry solution.

Prefabricating concrete slabs with already inserted shear connectors and finally assembling timber beams moves work from the construction site to the work-shop.

The aim of this paper is to present an experimental study on 7 series of different connector types already embedded into the prefabricated concrete slab. The principal objective of testing various shear connectors was not only to investigate different parameters of the fasteners as stiffness (slip modulus), strength and ductility but it was in addition intended for evaluating prefabrication process potentials. It was decided to evaluate a range of fasteners with either strong and rigid mechanical performance or with a reduction of strength and stiffness but high ductility. The experimental results as stiffness and strength are presented and discussed.

2. Shear test program

2.1 Shear test set-up

The shear tests were performed in 7 series of different connector types in order to obtain their load-slip relationship. A grand total of 28 specimens (4 samples in each test batch) were tested with an experimental set-up as presented in Fig. 1.

Fig. 1 Shear test set-up

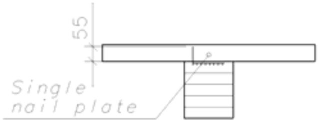
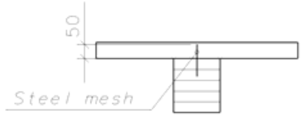
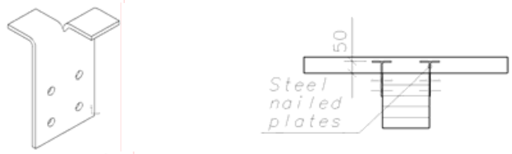
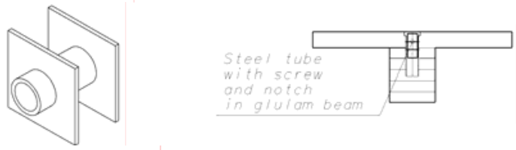
An asymmetrical test specimen was selected due to the prefabricated concrete slab. The asymmetrical shear test set-up overestimates the load and the slip modulus. No measurements of the horizontal reaction were taken.
Each test sample consisted of one prefabricated concrete slab, strength class K30 (according to Swedish code), 60x400x400mm^3 with inserted shear connector and one glued laminated member, strength class L40 (according to Swedish code), 115x135x400mm^3.

The shear tests were carried out according to ISO 6891-1983 (E) which also includes methods how to determine stiffness of the connectors. Preliminary tests prefaced each series to characterize the estimated load F_{est} and the rate of load application. The tests were run until ultimate load or 15 mm slip was reached. To measure slip between the concrete slab and the glulam element one LVDT transducer was mounted on each side, Fig.1. Data was sampled with a frequency of 2 Hz (i.e. every 0.5s). Load was applied using a DARTEC hydraulic jack with an accuracy of 1% over the load range 0-600 kN.

2.2 Shear test programme-types of connectors

The seven different connectors are presented in Table 1.

Table 1 Shear connectors programme

Type	Description of the connectors	
SNP	Nailplate, bent at an angle of 90°, moulded into the slab	
SM	A continuous steel mesh embedded into the prefabricated slab and epoxy-glued into a slot in the glulam beam	
DST+S	A set of 2 steel tubes inserted into the concrete slab with screws Ø20x120mm. The distance between tubes was 250mm.	
SP+N	Bent steel plates set into the slab and nailed to both sides of the glulam beam with 8 nails 4.5x75 mm.	
GSP	Bent steel plate set into the slab and epoxy-glued into a slot in the glulam beam.	
ST+S+N	A set of steel tube inserted into the concrete slab with screw Ø20x160mm and a notch in the glulam beam.	
GDF	Dowel Ø20x120mm with flanges embedded into the concrete slab and epoxy-glued into a hole in the glulam beam.	

The connector type SNP was a nailplate previously investigated by [2]. Fig. 2 presents prefabricated concrete slab with nailplate in three phases.

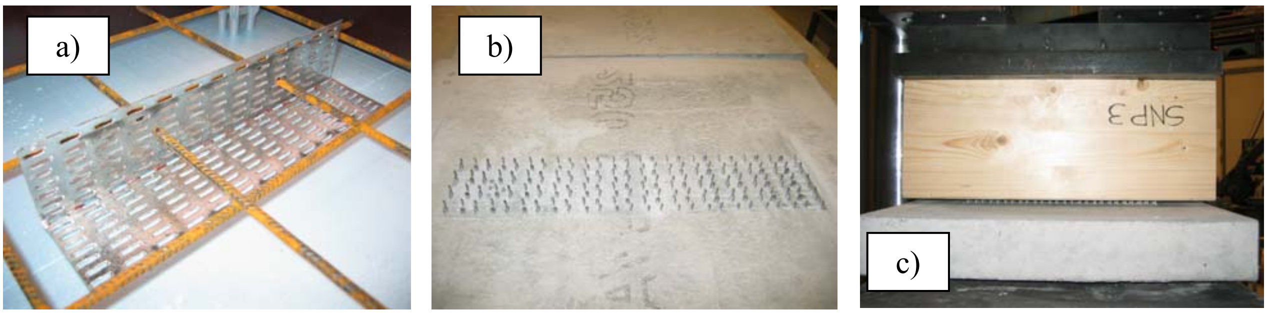


Fig. 2 Nailplate connector type a) in moulding form, b) prefabricated slab, c) pressing glulam member into concrete slab

The length of the nailplate was 250mm and it was manufactured from common nailplates with 8 mm long nails. The nails were pressed into the glulam beam using a hydraulic jack with a 100kN load. The pressing process created compression stresses nearly equal to the ultimate compression strength perpendicular to the grain and several cracks in the mid-section of the beam appeared.

Two component epoxy StoBPE 465/464 available on the Swedish market was used for bonding steel parts to wooden members in SM, GSP and GDF series. Glue connections proved in previous studies [4] almost full composite action. The joint was realized by filling slots and holes to 2/3 of the depth with epoxy. Slots prepared in glulam beams for SM and GSP series and holes in GDF specimens were approximately 2 mm wider than the dimensions of the steel parts to make sufficient room for epoxy glue. Plastic foil was placed between concrete slab and glulam beam surfaces, to eliminate undesirable bond. Specimens from SM, GSP, GDF series, were tested 7 days after gluing to provide full curing of epoxy. Prefabricated concrete slabs with inserted steel mesh, steel plate and dowel before gluing procedure are presented in Fig. 3.

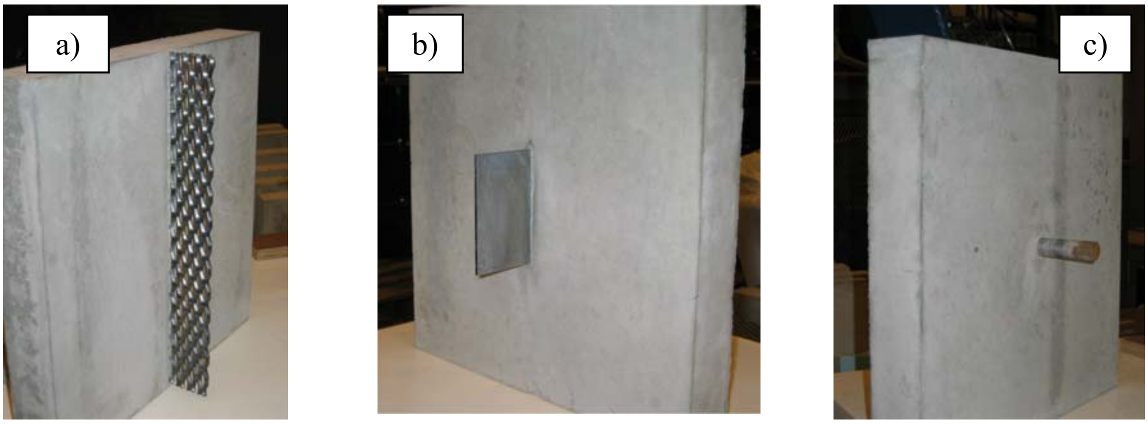
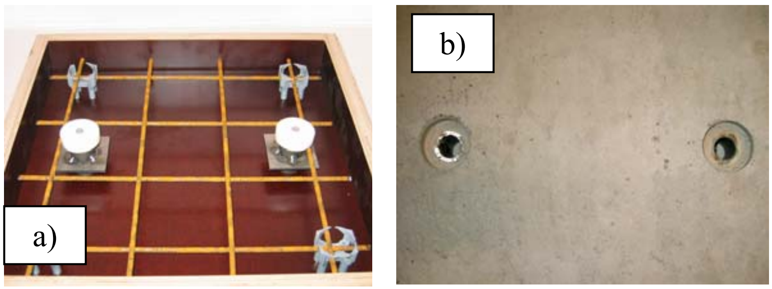
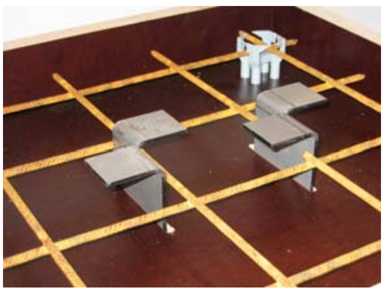


Fig. 3 Concrete slabs with inserted shear connectors a) SM steel mesh, b) GSP steel plate, c) GDF steel dowel



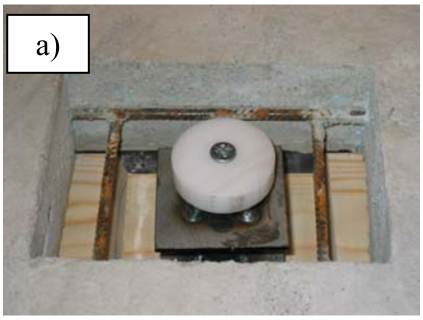
Steel tubes with one flange, illustrated in Fig. 4, with an inner diameter of 20mm and a length of 48mm set for screws were made for the DST+S series. Each screw was pre-tensioned with 130Nm using a torque wrench.

Fig. 4 Steel tube shear connector a) in moulding form with screwed plastic caps to create room for the screw head, b) prefabricated slab



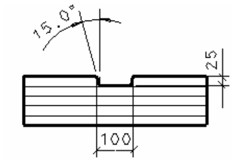
In Fig. 5 a pair of steel plates forms a shear connector system (GSP) which was nailed to the glulam beam by means of 8 nails Ø4.5x75mm. A 10mm displacement between plates, was made to provide overlap of the fasteners. The flanges folded in the steel plate act as anchorage in concrete slab. The total length of the plate was 160mm and the width 75mm measured in the holes plane.

Fig. 5 Steel plate shear connector adjusted in the moulding form



A steel tube shown in Fig. 6a), with a length of 67mm, with two welded flanges, together with a screw Ø20x160mm placed above a notch in the timber beam is the ST+S+N series. A prefabricated concrete slab with a rectangular hole 115x120mm^2 was placed on top of the glulam member. The hole was filled with concrete mix and tests were performed after 28 days from the filling operation. The screw was pre-tensioned with 130Nm using a torque wrench.

b)



The notch in the glulam had a 15^o slope and a width of 100mm measured at 25mm depth.

Fig. 6 ST+S+N type connector a) steel tube connector adjusted to glulam beam with screwed plastic cap to create a head for the screw, b) notch in glulam beam

3. Test results

Load-slip representatives presented in Fig.7 correspond to mechanical behavior of each tested shear connector. Numerical characteristics are given in Table 2. Type ST+S+N connector had the highest resistance while the highest initial stiffness was obtained by the SM type connector. The maximum load reached by the SM connector is 25% less than obtained by the ST+S+N connector. Connector types DST+S and GSP reached equivalent resistance however the stiffness of the DST+S connector is only 8% of the GSP connector, the lowest slip modulus of all tested connectors.

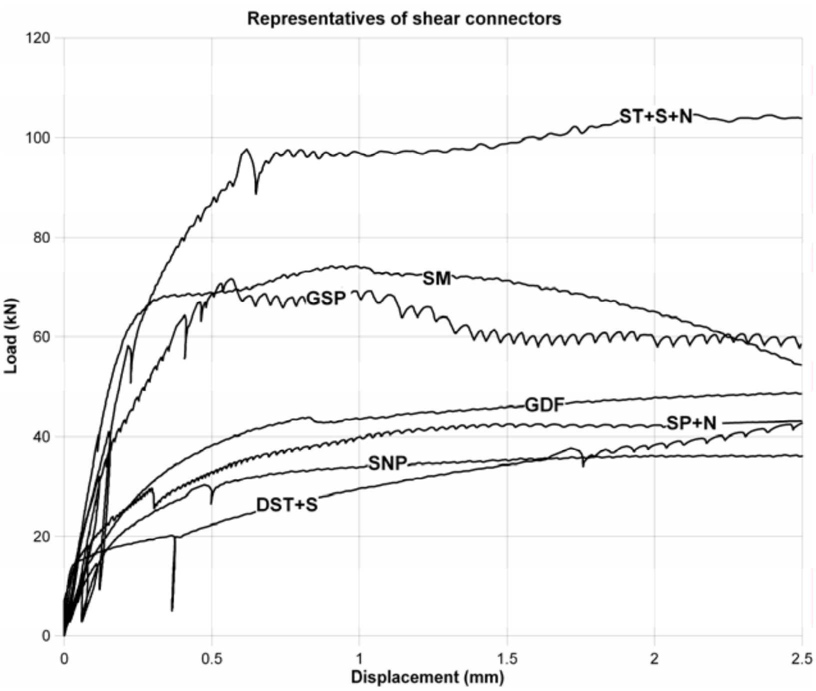


Fig. 7 Shear test results, load-slip curves representatives of all test specimens

Average maximum load and slip modulus for all shear connectors are presented in Fig. 8a-b).

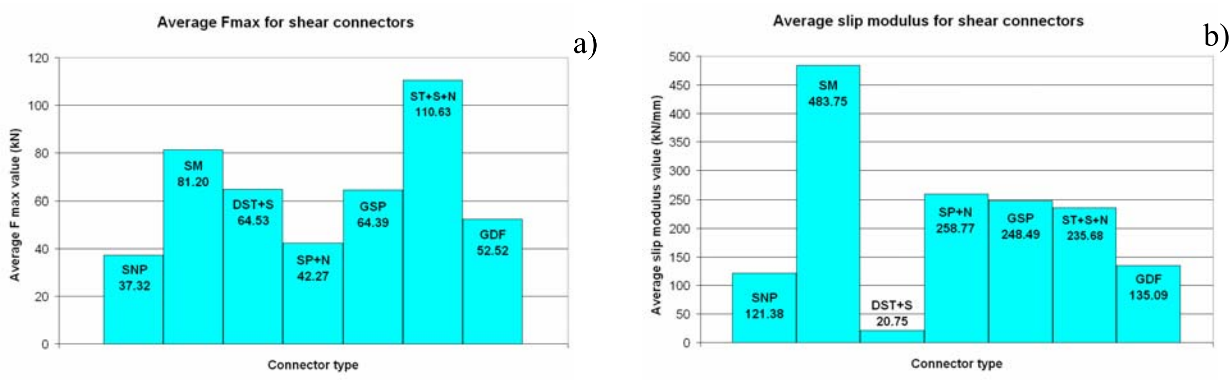


Fig. 8 Shear test results a) average failure load, b) average slip

The largest spread in maximum load is for GSP connector type, though for the slip modulus it is for DST+S, Table 2.

Table 2 Shear test results

Type	Range of failure load [kN]	Mean failure load [kN]	Standard deviation [kN]	COV [%]	Range of slip modulus values [kN/mm]	Mean slip modulus [kN/mm]	Standard deviation [kN/mm]	COV [%]
SNP	35.4-38.9	37.3	1.64	4.4	95.3-135.2	121.4	18.0	14.8
SM	74.3-88.1	81.2	5.66	7.0	377.0-595.8	483.8	90.8	18.8
DST+S	59.8-68.8	64.5	3.71	5.8	7.5-43.3	20.7	15.8	76.2
SP+N	36.8-47.0	42.3	4.28	10.1	80.8-412.0	258.8	166.6	64.4
GSP	43.3-73.4	64.4	14.15	22.0	118.2-325.9	248.5	90.4	36.4
ST+S+N	99.6-126.7	110.6	14.22	12.9	221.3-245.6	235.7	12.8	5.4
GDF	51.0-54.8	52.5	1.62	3.1	120.0-174.6	135.1	26.5	19.6

Table 3 Shear test results, $v_{i,mod}$-modified initial slip, $v_{0.6,mod}$ and $v_{0.8,mod}$-modified slip at 0.6 and 0.8 F_{est} respectively

Test specimen	Slip		
	$v_{i,mod}$ mm	$v_{0.6,mod}$ mm	$v_{0.8,mod}$ mm
SNP	0.11	0.23	0.46
SM	0.05	0.11	0.17
DST+S	1.69	3.03	4.88
SP+N	0.10	0.23	0.50
GSP	0.10	0.23	0.41
ST+S+N	0.13	0.22	0.43
GDF	0.14	0.33	0.65

Table 3 presents modified slip at a load level of 40%, 60% and 80% of the maximum load. The displacements were obtained according to ISO 6891-1983 (E). The type connector SM had the lowest slip while connector type DST+S had the highest slip, above 1 mm at a load level of 40% of the ultimate load. The slip at $0.8F_{est}$ was 4.88mm and no failure occurred during the entire test.

Results for four of the tested connectors, for all replications, by means of load-slip curves are presented in Fig. 9 and Fig. 11. Results for the DST+S shear connector are shown in Fig. 9a). The characteristic failure of the connector is presented in Fig. 10a). The DST+S type connector appeared as the most ductile system due to the ability to carry load under large deformation. Resistance was still increasing after 15mm slip different from all other tested connectors. Slip modulus for SP+N connector, Fig. 9b) was the second after the SM series. The tests were stopped when the concrete started to crack although the maximum load was not reached. Fig.10b) presents characteristic failures in SP+N type connectors. The crack in the concrete slab occurred due to the rotation of the steel plate. Shear failure in one nail was observed at the interface between steel plate and glulam beam.

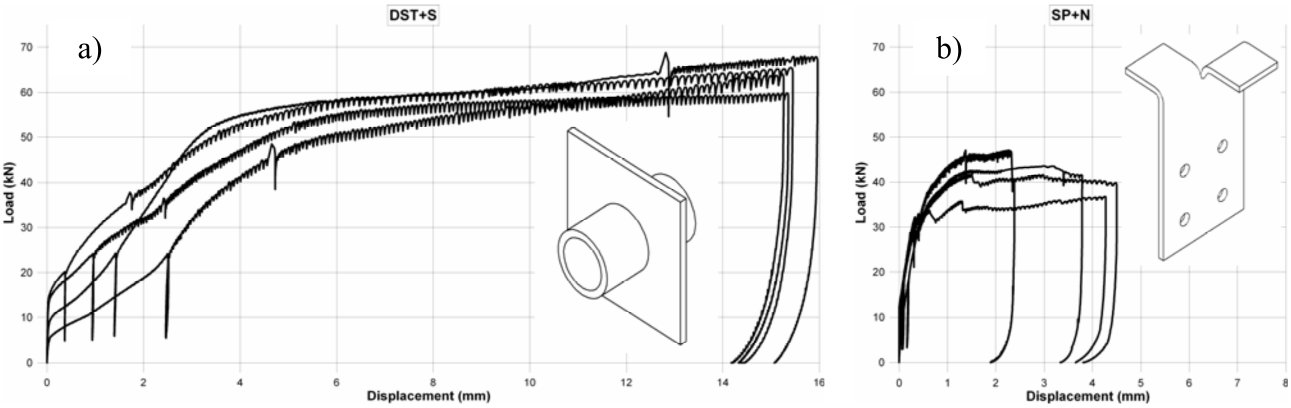


Fig. 9 Load-slip curves for shear connector types a) DST+S and b) SP+N.

Fig. 10c) presents the failure in the nailplate type connector SNP. Yielding of the plate took place after cracks in concrete occurred.

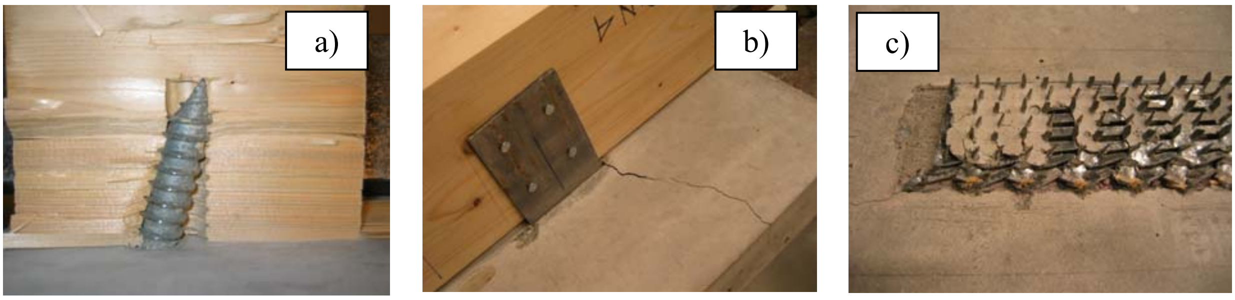


Fig. 10 Failure in connector types a) DST+S, b) SP+N, c) SNP,

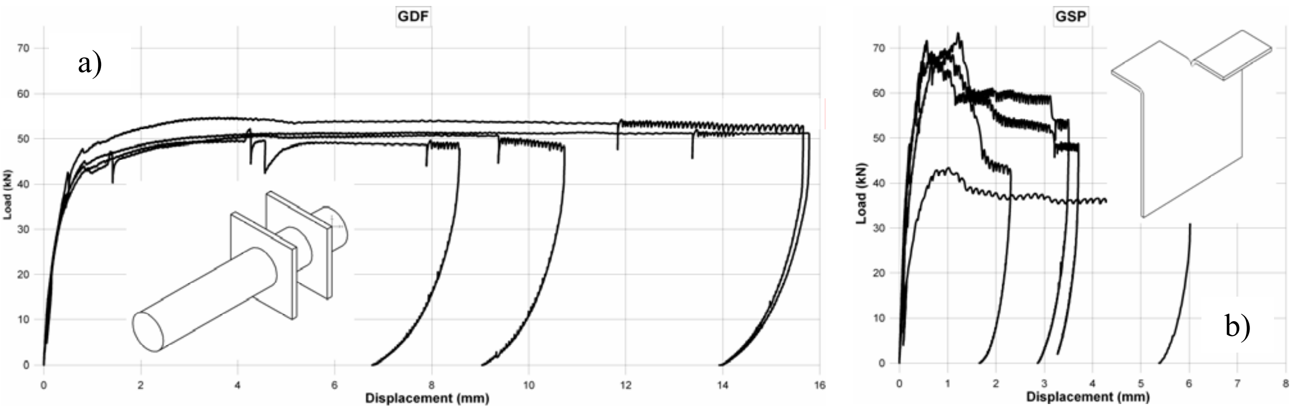


Fig. 11 Load-slip curves for shear connector types a) GDF and b) GSP

Tests results of GDF type connector are presented in Fig.11a). The load-slip curve shows elasto-plastic behavior which corresponds to classical behavior of dowel-type connectors. The tests were stopped when the first cracks occurred in the concrete slabs. Cracks propagated perpendicular to the glulam beam on both sides of the dowel. For the GSP type connector the results are shown in Fig. 11b). This type of connector shows an increase in load capacity, but once the maximum load is reached the resistance decreases. Final failure of the system was due to the failure in the concrete slabs. The failure of the GSP system was similar to the connector type with a pair of steel plates with nails, Fig. 10b). For the SM shear connector the failure took place in concrete, cracks appeared along the mesh line and secondly yielding of the mesh followed. Failure in the concrete notch was the failure mode for the ST+S+N shear connector.

The material properties of glulam after shear tests were checked and the mean density of glulam was 417.6kg/m^3 and the mean moisture content 11%. Average compression strength of concrete was 43MPa, 47MPa, 51MPa, 53MPa, while the concrete cubes (150x150x150mm^3) were tested after 7, 14, 28 and ~35 days respectively. The average compression strength of concrete was measured through a compression test on three cubes.

4. Analysis and discussion

It is feasible to manufacture timber-concrete structures as fully pre-fabricated elements. The system with shear connectors inserted into the prefabricated concrete slabs, besides reducing costs and time during preparation process, eliminates completely the shrinkage problem existing in current proposed techniques of combining timber and concrete materials. From the shear tests results the conclusion can be drawn that it is achievable stiff (SM, GSP, ST+S+N) and ductile (SNP, DST+S, SP+N, GDF) "dry-dry" connections. To increase load-carrying capacity and stiffness of the system with DST+S it is doable to use longer screws. The stiffness of the connectors described by slip modulus was in the range 20.75÷483.75 (kN/mm). Furthermore the resistance of the connectors varied between 37.32÷110.63 (kN). Both stiffness and resistance compare well to the properties of mechanical connectors used in wet-dry techniques [1-5].

For further investigations of new "dry-dry" shear connectors the two simple, economical and relatively stiff connector types DST+S and SP+N were chosen for full scale tests. Ongoing research project involves bending tests and dynamic tests of the entire system. Long term tests are also planned.

5. References

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